
LBNE Update
R.Svoboda, FNAL PAC,16 October, 2012

Topics Covered

- Scientific Opportunity
- Phasing of the LBNE Project
- Challenges
- Schedule

The Vision

- A powerful, upgradable neutrino beam at a distance matched to the Δm^2_{13} oscillation length of L/E ~ 500 to measure the neutrino mass hierarchy, look for CP violation, and make precision measurements of the oscillation model in search of new physics.
- A large underground detector capable of extending the search for proton decay, making very large L/E measurements with atmospheric neutrinos, and detecting a galactic supernova.
- An advanced Near Detector comparable to the precision of the long baseline measurement.

The Opportunity

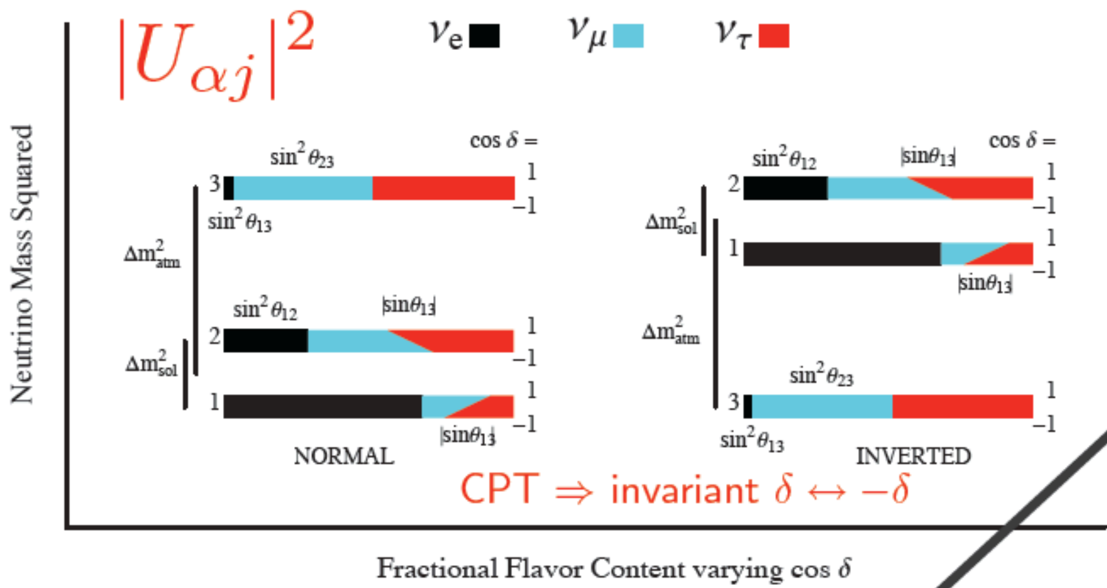
- Since 1998 we have been methodically measuring the parameters of neutrino oscillations in a 3-component scenario.
- The goal of this campaign was to be able to predict neutrino flavor oscillations to a precision that allows us to test underlying assumptions of our model.
- We can also use our hard-won knowledge in other areas of science where neutrinos are used as a probe.

Progress!

	Free Fluxes + RSBL	
	bfp $\pm 1\sigma$	3σ range
$\sin^2\theta_{12}$	0.30 ± 0.013	$0.27 \to 0.34$
$\theta_{12}/^\circ$	33.3 ± 0.8	$31 \to 36$
$\sin^2\theta_{23}$	$0.41^{+0.037}_{-0.025} \oplus 0.59^{+0.021}_{-0.022}$	$0.34 \to 0.67$
$\theta_{23}/^\circ$	$40.0^{+2.1}_{-1.5} \oplus 50.4^{+1.2}_{-1.3}$	$36 \to 55$
$\sin^2\theta_{13}$	0.023 ± 0.0023	$0.016 \to 0.030$
$\theta_{13}/^\circ$	$8.6^{+0.44}_{-0.46}$	$7.2 \to 9.5$
$\delta_{\mathrm{CP}}/^\circ$	300^{+66}_{-138}	$0 \to 360$
$\dfrac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$	7.50 ± 0.185	$7.00 \to 8.09$
$\dfrac{\Delta m^2_{31}}{10^{-3}\ \mathrm{eV}^2}$ (N)	$2.47^{+0.069}_{-0.067}$	$2.27 \to 2.69$
$\dfrac{\Delta m^2_{32}}{10^{-3}\ \mathrm{eV}^2}$ (I)	$-2.43^{+0.042}_{-0.065}$	$-2.65 \to -2.24$

When I was a postdoc all these numbers were thought to be zero by many smart people.

We are lucky that nature can be kind sometimes.



Both quantities are fortunately just right for a practical laboratory experiment.

$\delta m^2_{sol} = +7.6 \times 10^{-5}\ eV^2$ $\quad$ $\sin^2\theta_{12} \sim 1/3$

$|\delta m^2_{atm}| = 2.4 \times 10^{-3}\ eV^2$ $\quad$ $\sin^2\theta_{23} \sim 1/2$

$|\delta m^2_{sol}|/|\delta m^2_{atm}| \approx 0.03$ $\quad$ $\sin^2\theta_{13} = 0.023$

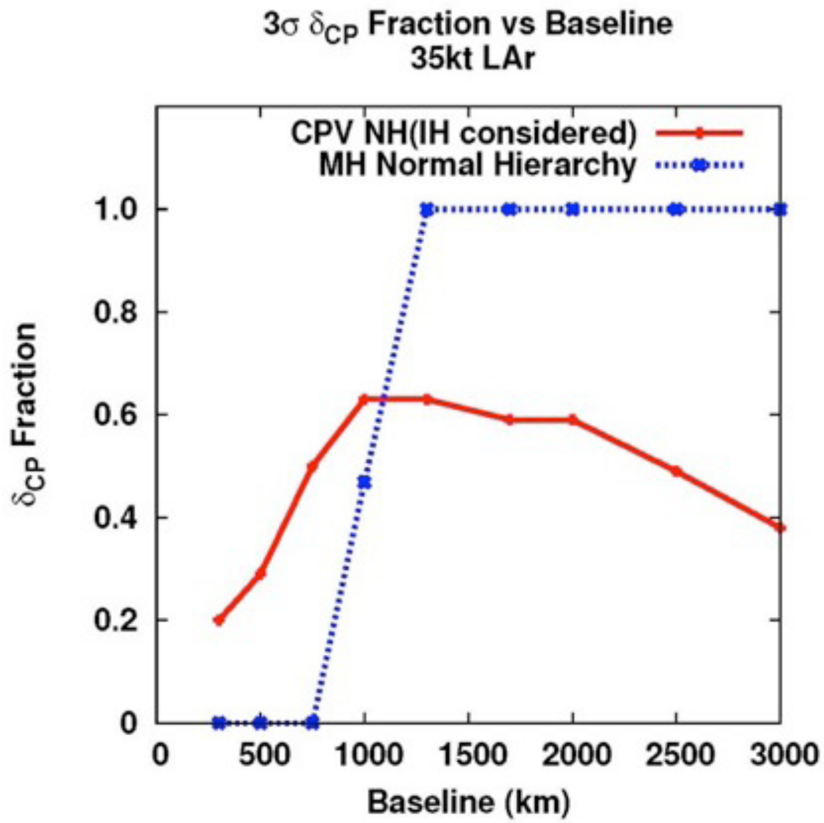
$\sqrt{\delta m^2_{atm}} = 0.05\ eV < \sum m_{\nu_i} < 0.5\ eV = 10^{-6} * m_e$ $\quad$ $0 \leq \delta < 2\pi$

$\theta_{12} \approx \theta_{sol} \approx 34°,\ \theta_{23} \approx \theta_{atm} \approx 37\text{-}53°,\ \theta_{13} = 9°$

δ would lead to $P(\overline{\nu}_\alpha \rightarrow \overline{\nu}_\beta) \neq P(\nu_\alpha \rightarrow \nu_\beta)$. $\cancel{CP}$

Since there are 3 neutrinos, there must be a 3x3 matrix with 3 angles and 1 phase (observable) and 2 Δm^2. LBNE will determine if this holds true.

- Design for LBNE started well before we knew all necessary oscillation parameters
- Nevertheless, the P5 report recommended early investment in a long baseline experiment
- This has paid off. The Fermilab program is best positioned right now.



This calculation optimizes the beam from the Main Injector and calculates the stand alone sensitivity of LBNE.

5(+5) years of running of neutrino (+antineutrino) running with a full 35 kT detector.

LBNE

LBNE Phasing

- Due to the high cost of the full LBNE, we were asked to present a phased program, with the first phase being "affordable" under current budgets.
- A Reconfiguration Steering Group was formed by Fermilab to consider possible options.
- The committee worked with a large group of people from the LBNE collaboration to come up with apples-to-apples comparisons among possible options

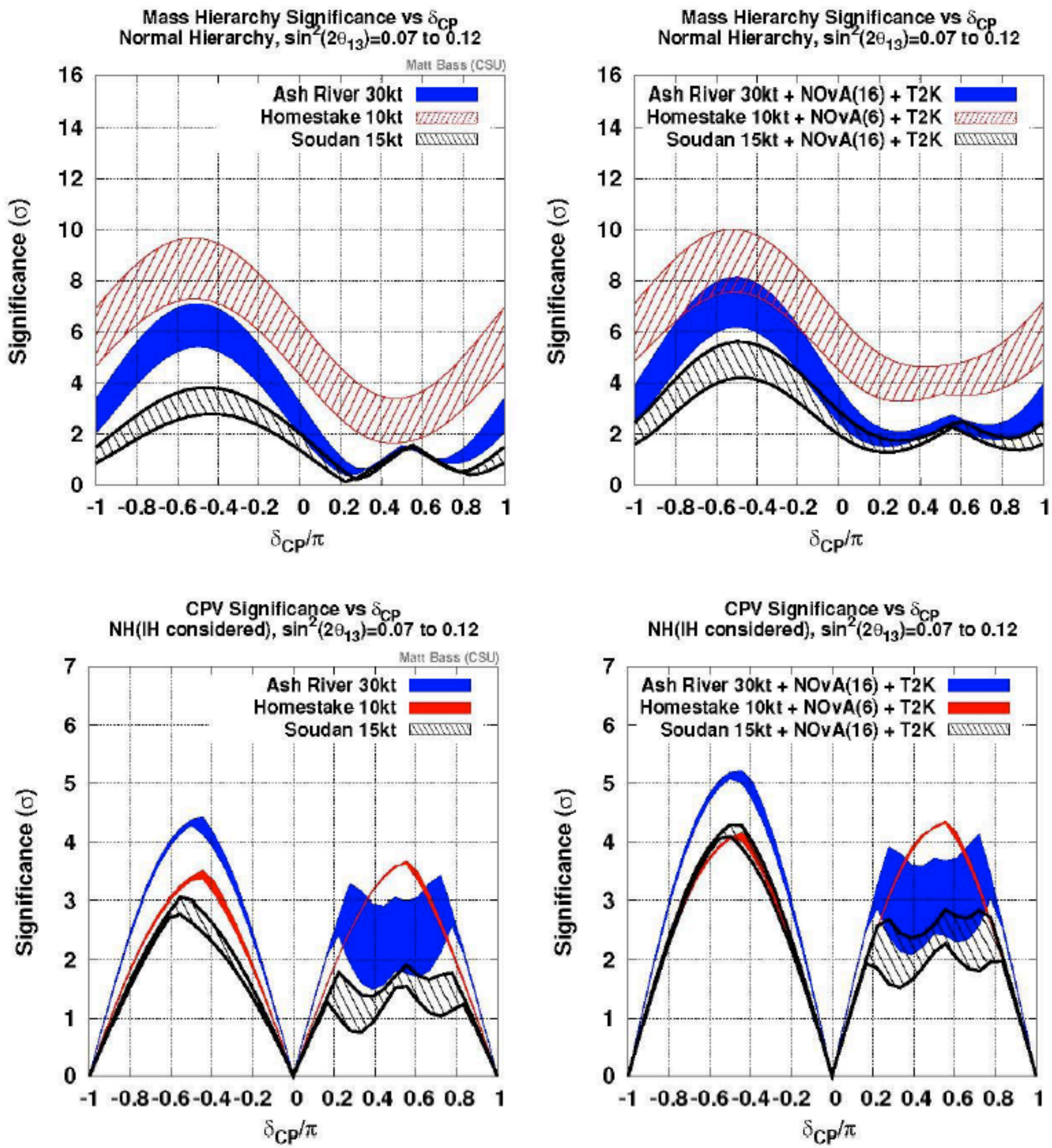
The Steering Committee

Steering Committee

Membership	Institution
Jon Bagger	JHU
Charlie Baltay	Yale
Gary Feldman	Harvard
Young-Kee Kim , Chair	Fermilab
Kevin Lesko	LBNL
Ann Nelson	UW Seattle
Mark Reichanadter	SLAC
Mel Shochet	Chicago
Bob Svoboda	UC Davis
James Symons	LBNL
Steve Vigdor	BNL

Ex-officio group

Membership	Institution (comments)
Andy Lankford	UC Irvine (HEPAP chair, DUSEL NRC study chair)
Steve Ritz	UC Santa Cruz (PASAG chair)
Jay Marx	Caltech (DUSEL review committee co-chair)
Pierre Ramond	U. Florida (DPF chair)
Harry Weerts	ANL (Intensity Frontier Workshop co-chair)
JoAnne Hewett	SLAC (Intensity Frontier Workshop co-chair)
Jim Strait	FNAL (LBNE Project Director, Engineering/ Cost WG deputy chair)
Pier Oddone	FNAL (Director, Fermilab)
Susan Seestrom	LANL (LBNE Lab Oversight Group member)

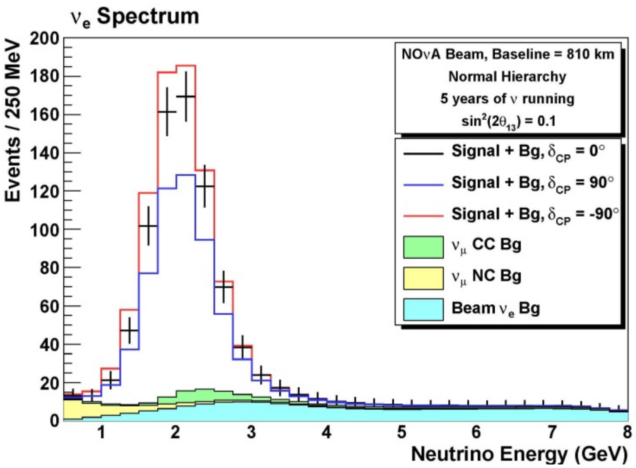


Options with Soudan, Ash River, and Homestake were considered.

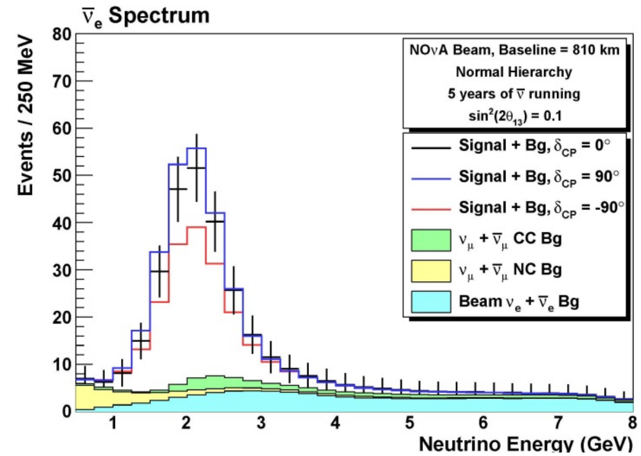
Only options thought to be "affordable" were considered for phase 1.

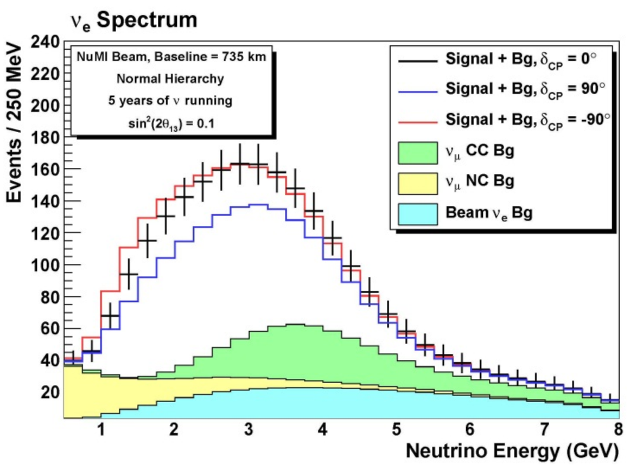
Inclusion of data from NOVA and T2K was taken into account, as was possible variation in input parameters

It was also useful to look at expected spectra

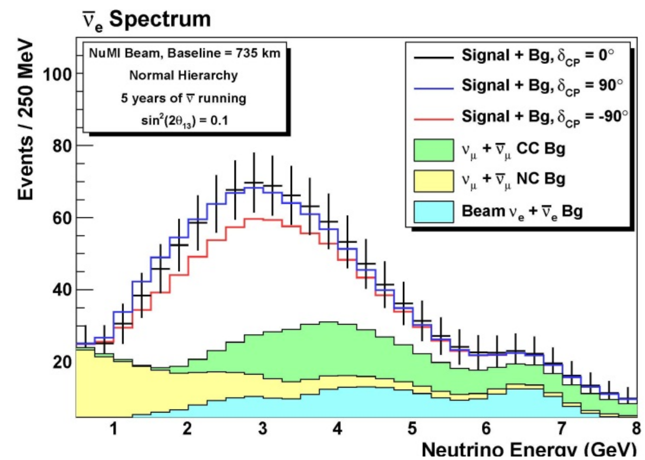


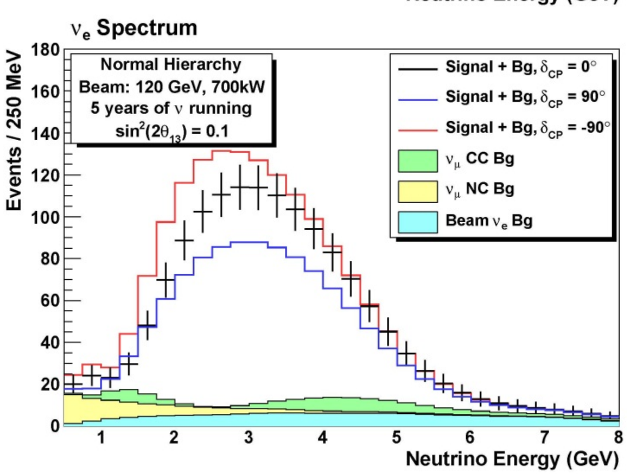
Ash River



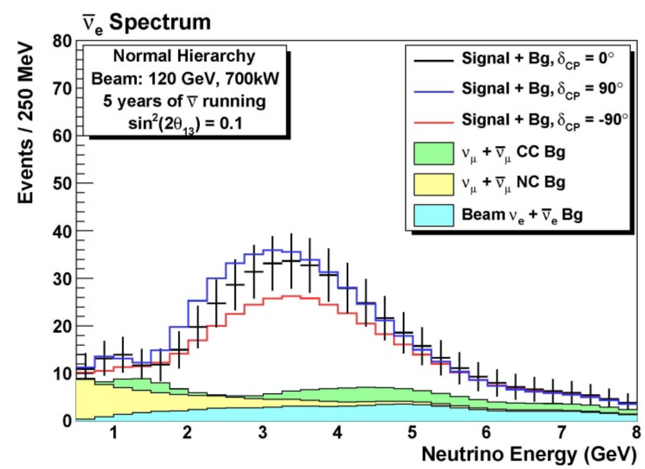


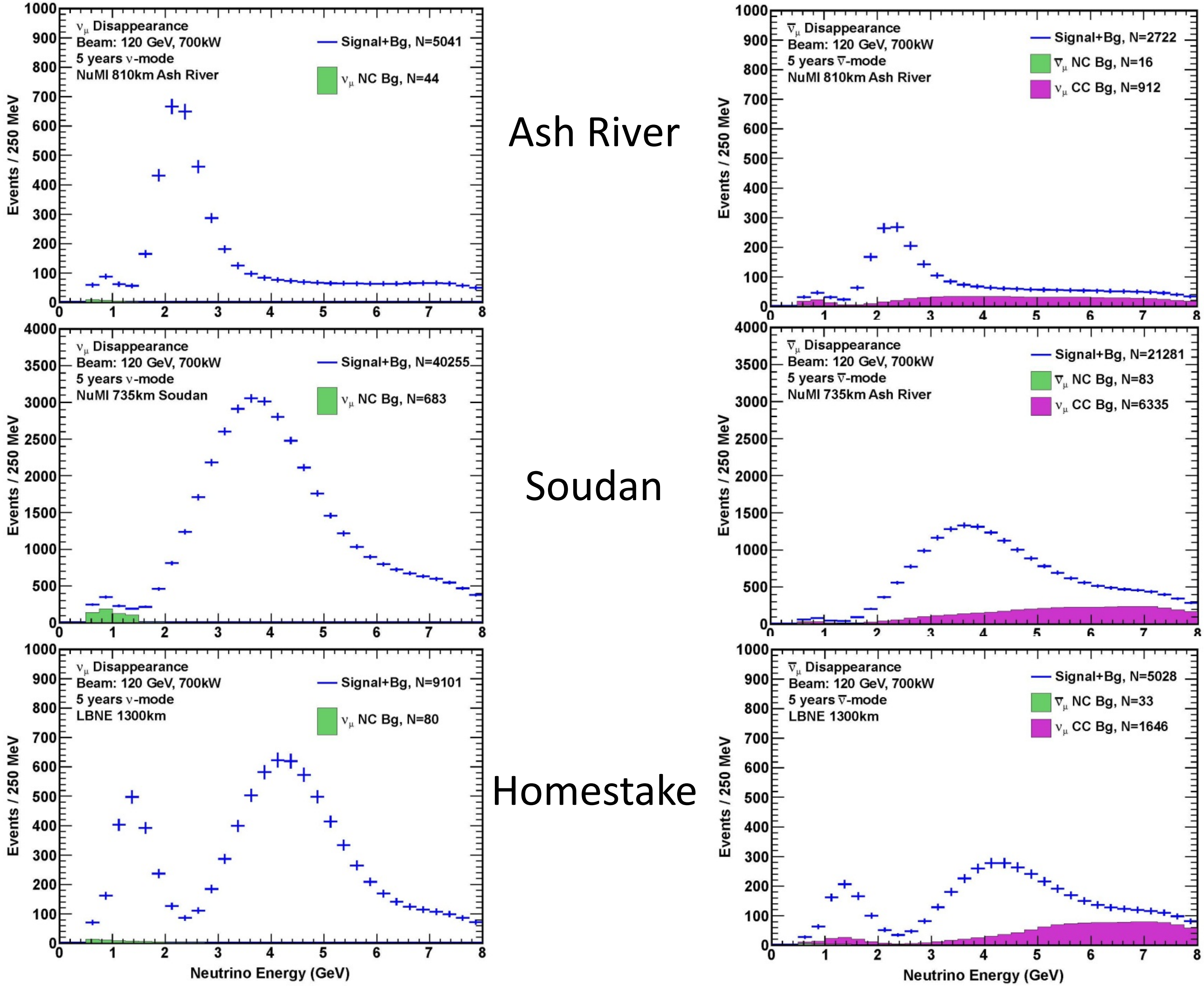
Soudan





Homestake





Ash River
Soudan
Homestake
νμ Disappearance
Beam: 120 GeV, 700kW
5 years ν-mode
NuMI 810km Ash River
Signal+Bg, N=5041
νμ NC Bg, N=44
ν̄μ Disappearance
Beam: 120 GeV, 700kW
5 years ν̄-mode
NuMI 810km Ash River
Signal+Bg, N=2722
ν̄μ NC Bg, N=16
νμ CC Bg, N=912
νμ Disappearance
Beam: 120 GeV, 700kW
5 years ν-mode
NuMI 735km Soudan
Signal+Bg, N=40255
νμ NC Bg, N=683
ν̄μ Disappearance
Beam: 120 GeV, 700kW
5 years ν̄-mode
NuMI 735km Ash River
Signal+Bg, N=21281
ν̄μ NC Bg, N=83
νμ CC Bg, N=6335
νμ Disappearance
Beam: 120 GeV, 700kW
5 years ν-mode
LBNE 1300km
Signal+Bg, N=9101
νμ NC Bg, N=80
ν̄μ Disappearance
Beam: 120 GeV, 700kW
5 years ν̄-mode
LBNE 1300km
Signal+Bg, N=5028
ν̄μ NC Bg, N=33
νμ CC Bg, N=1646
Events / 250 MeV
Neutrino Energy (GeV)

Phase 1 Option		15 kton Soudan (underground)	30 kton Ash River (surface)	10 kton Homestake (surface)
Phase 1 Science Capabilities assuming 6×10^{21} protons on target or 10 years with 700 kW	Mass Hierarchy: fraction of δ_{CP} at 3σ	0.17 (0.38)	0.47 (0.50)	0.81 (1.00)
	CP Violation: fraction of δ_{CP} at 3σ	0.05 (0.23)	0.27 (0.55)	0.27 (0.45)
	Resolution of δ_{CP} $\delta = 0, 90^\circ$	$23^\circ, 30^\circ$ $(14^\circ, 26^\circ)$	$18^\circ, 29^\circ$ $(13^\circ, 25^\circ)$	$17^\circ, 30^\circ$ $(12^\circ, 25^\circ)$
	Proton Decay $p \rightarrow K\nu$ 90% CL in 10 years	1×10^{34} years	No	No
	Number of observed neutrinos from a supernova explosion at a distance of 10 kiloparsecs	1,300	No	No
	Atmospheric neutrinos Mass Hierarchy in 10 years	$1.5\ \sigma$	No	No
	Precision Measurements: $\sigma(\theta_{13})$ for $\delta=\pi/2$ Neutrino $\sigma(\theta_{23})$ Anti neutrino $\sigma(\theta_{23})$ Neutrino $\sigma(\Delta m_{31}^2)$ (10^{-3}eV^2) Anti neutrino $\sigma(\Delta m_{31}^2)$ (10^{-3}eV^2)	 0.60° 1.1° 1.3° 0.036 0.055	 0.40° 0.74° 1.1° 0.035 0.050	 0.40° 0.69° 0.97° 0.025 0.040
Phase 1 Risks	Work in progress	Geotechnical studies for the underground detector	Cosmic ray backgrounds in a surface detector	Cosmic ray backgrounds in a surface detector

Homestake was selected as the best option

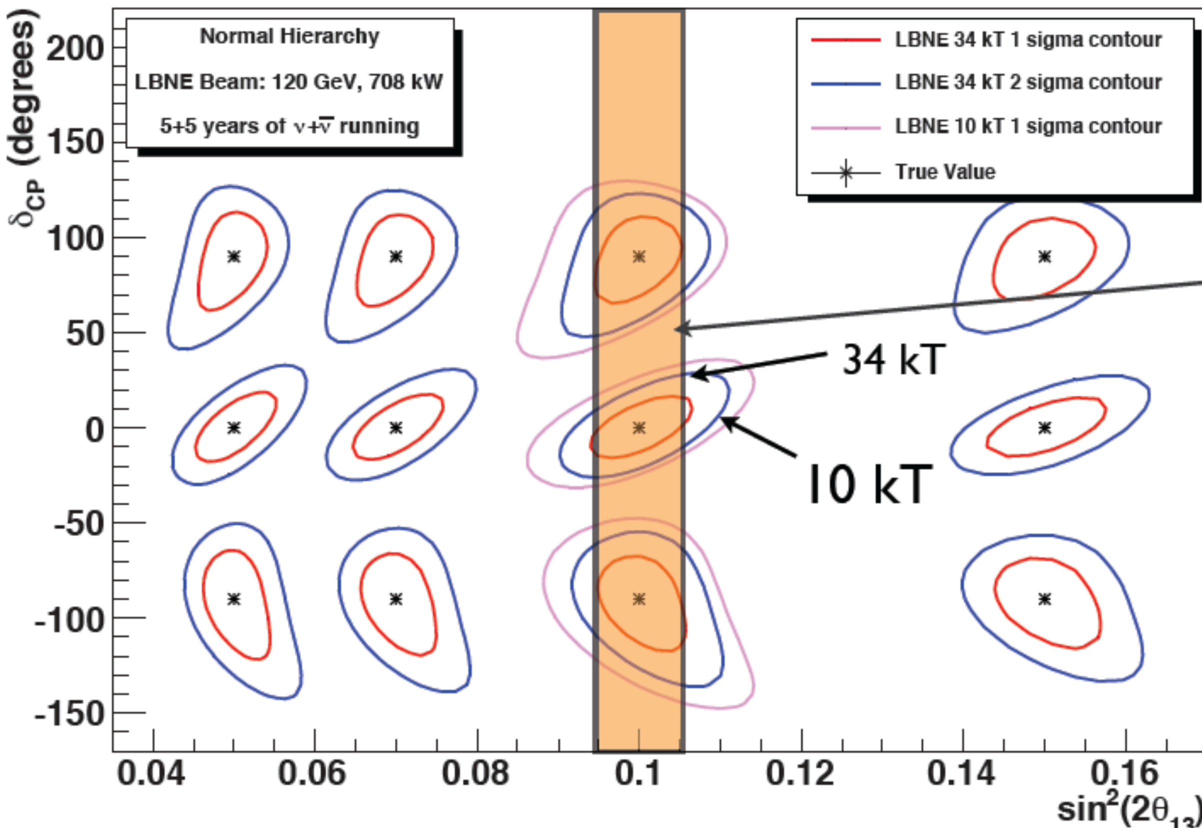
- It has the right baseline - selected by Nature
- Backgrounds are smaller as some are oscillated away.
- The beam would be upgradable to >2 MW
- The existence of an underground lab at the site may be important for future experiments
- Basically, we don't know what the physics of 2030 will be – preserve **flexibility**

Disadvantages

- Can only afford small detector – 10 ktons
- Can only afford surface location. Physics program is curtailed. It would cost ~$135M to move underground.
- No near detector (note: we only expect ~3 events/month so it will take some time until systematics become limiting, but obviously not an ideal situation. It would cost ~$60M-$70M to make an underground lab, plus additional funds for a near detector.

LBNE Parameter measurement

Phase I ν_e(anti-ν_e) ~50 (~20) events per year with >50% modulation



Expected final 1 sigma error from reactors (centered on 0.1)

- LBNE will have a definitive determination of the mass hierarchy.
- LBNE will have a measurement of the phase and θ_{13} with no ambiguities.
- The phase measurement will range from ±20 to ±30 deg for Phase I when combined with reactor data.
- Parameter measurement will continue to improve with statistics.

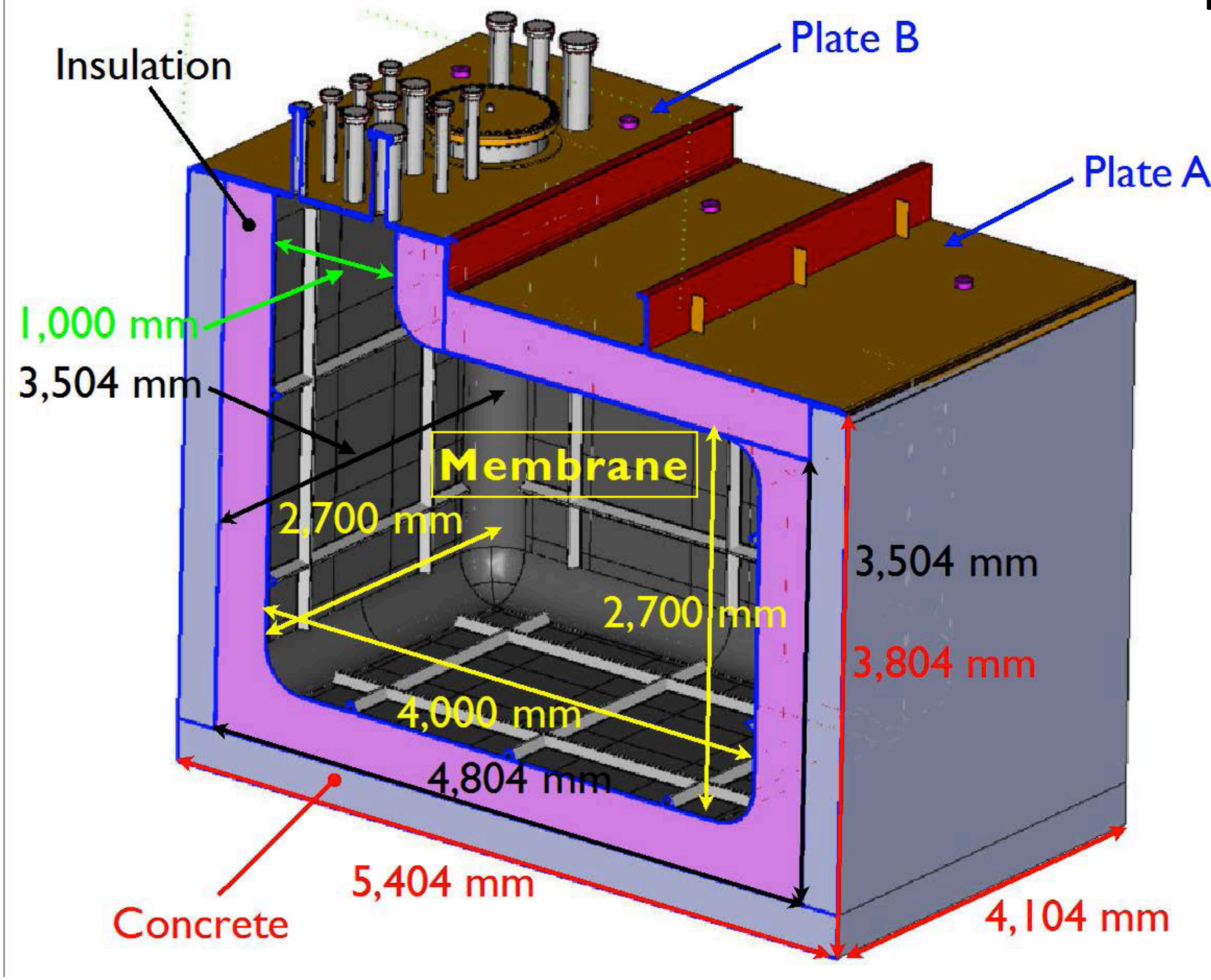
Current Status

- Successful Director's Review in September. No major problems.
- CD1 Review scheduled for end of October.
- **We are actively seeking international partners to help us recover some lost scope by helping to build the near and far detectors so we can move to an underground location.**
- Discussions with Brazil, India, Italy, and the U.K. are taking place.

Technical Challenges

- Building a large liquid argon detector. Maintain atability, learn how to calibrate a large detector, discover "unknown unknowns".
- Running a far detector on the surface (should this be required) is not trivial.
- Automatic event reconstruction is a big job

35 ton prototype

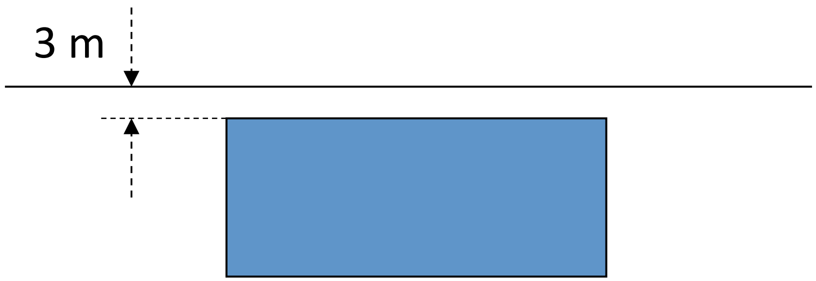


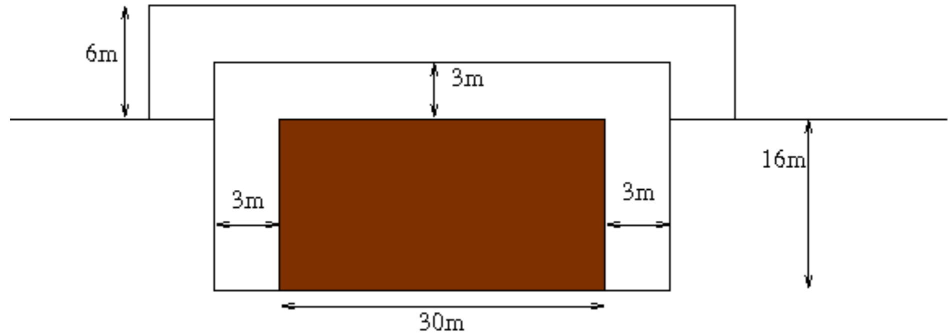
Will allow prototype deployment of many detector components

Surface Operation

- LArTPC's are relatively slow devices. A surface detector with 2.3 meter drift has 1.4 ms drift time. There would be ~70 muons in the detector during the drift time.
- Even though the beam spill may be 10 μsec, a scintillation light based trigger is needed to associate a track with the beam crossing time
- Collaboration has been studying how often could CR-generate showers mimic CC electron neutrino interactions.

Geometry





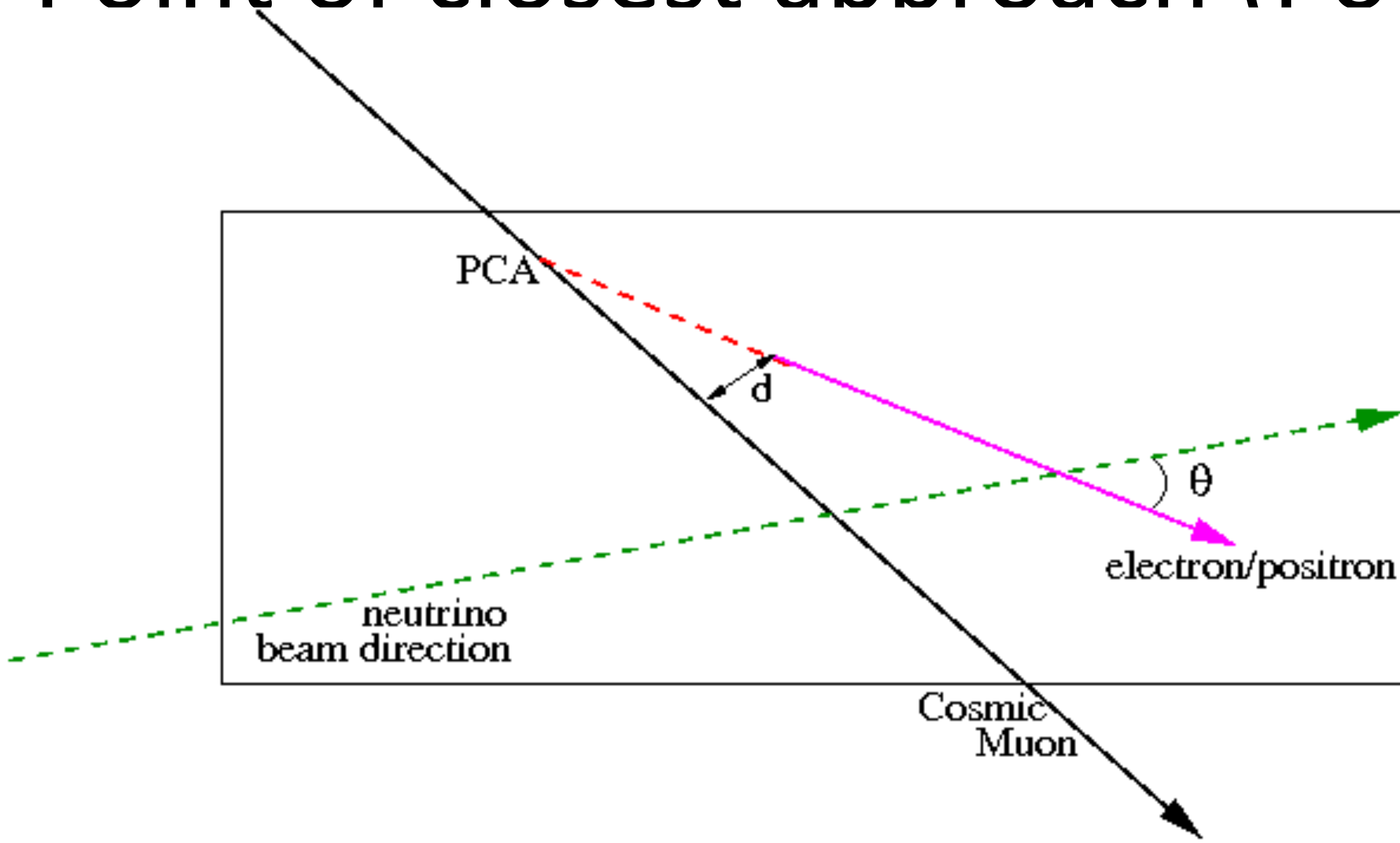
- Cuboid of liquid argon: 30 m long, 15 m wide, 16 m high; total mass 10 kt.
- 30 cm fiducial cut (9.1 kt fiducial mass).
- LAr is placed 3 m underground.
- Muons are coming from upper hemisphere although a few of them may scatter and come from below.
- GEANT4.9.5 for muon transport; physics list: Shielding (some simulations with QGSP_BERT).

Muons in the detector: summary table

Table 1: Rate of electrons with energy above 0.1 GeV per calendar year from different sources before and after cuts on PoCA (d) and energy. Columns from 2 to 6 shows event rates after specific cuts on PoCA and electron energy: column 2 – electron energy $E > 0.1$ GeV; column 3 – $E > 0.1$ GeV, PoCA $d > 10$ cm; column 4 – $E > 0.25$ GeV, PoCA $d > 10$ cm; column 5 – $E > 0.25$ GeV, PoCA $d > 30$ cm (this column gives an estimate for the expected rate of events since PoCA evaluation has been done for γ's, not electrons). The last column shows additional cut on fiducial volume: events starting within 30 cm from the walls are rejected. The simulated statistics corresponds to 0.047 of the calendar year. The figures in this Table do not account for an efficient ($\approx$98%) $e-\gamma$ separation factor [13] or for a reduction of the time window due to the efficient photon detection system.

	Rate per year				
Source of electrons	$E > 0.1$ GeV	$E > 0.1$ GeV $d > 10$ cm	$E > 0.25$ GeV, $d > 10$ cm	$d > 30$ cm (estimate)	30 cm from the walls
Knock-on electrons and e^+e^- pairs, $\mu \to e^\pm$	1.25×10^8	< 1000	< 100	~ 0	~ 0
Charged particles (not muons) or from outside	3.04×10^6	1.33×10^4	2.68×10^3	~ 0	~ 0
$\pi^0 \to e^\pm$	2.47×10^3	447	170	~ 70	~ 70
$K_L^0 \to e^\pm$	~ 100	< 100	~ 0	~ 0	~ 0
$\mu \to \gamma \to e^\pm$	1.28×10^6	< 100	< 100	~ 0	~ 0
$\pi^0 \to \gamma \to e^\pm$	3.02×10^5	4.47×10^4	2.01×10^4	8.4×10^3	$\sim 8 \times 10^3$
outside $\gamma \to e^\pm$	1.61×10^6	1.93×10^4	4.55×10^3	1.8×10^3	~ 200

Point of closest approach (PoCA)



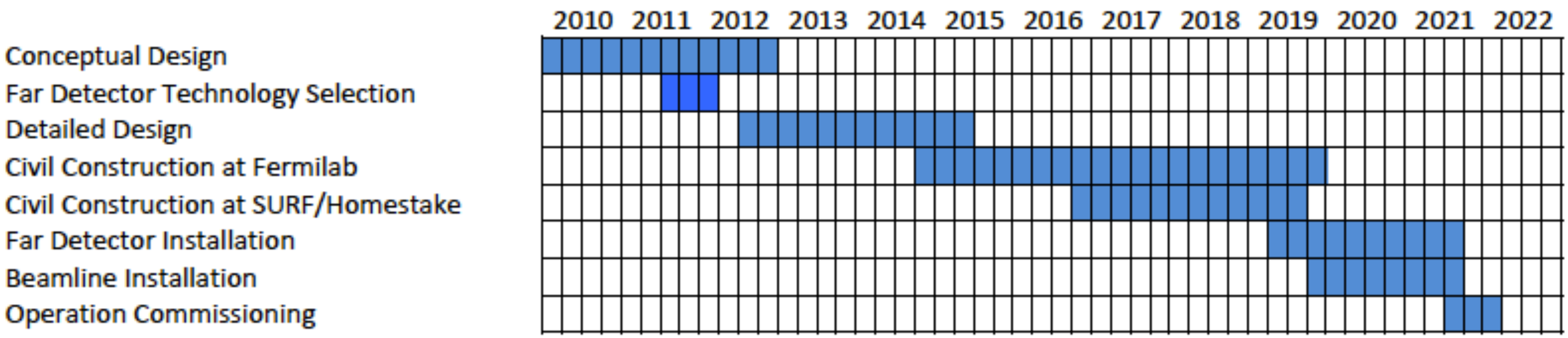
- PoCA has been calculated for each e^- or e^+ with $E > 0.1$ GeV produced by the first photon in a cascade.
- Also for photons.

- The collaboration studied background from: (a) muons passing through the detector, (b) muons passing outside the detector, and © incoming fast neutrons
- using PoCA and energy are effective in reducing much of the background associated with through-going muons. Expected 98% e/gamma separation is also used.
- A 30-cm fiducial volume cut is effective against nearby muons
- An effective photon detection system can also be effective.

Table 6–7: Cosmic ray backgrounds that produce electromagnetic showers in the detector and the expected event rate/yr after various selection critiria are applied. The initial background event rate is calculated assumning a 1.4 ms drift time per beam pulse, a beam pulse every 1.33 seconds and 2×10^7s of running/yr. The detector is assumed to be on the surface with 3m of rock overburden.

Background	$E_e > 0.25$ GeV	PoCA > 10cm	Fid > 30cm	Beam angle	e/γ PID	Beam timing
Muons in the detector						
$\mu^\pm \rightarrow e^\pm$	3.3×10^7	64	0	0	0	0
$\pi^0, K_L^0 \rightarrow e^\pm$	940	170	170	68	68	0.5
$\pi^\pm, K^\pm, ... \rightarrow e^\pm$	7.4×10^5	2.7×10^3	43	17	17	0.12
$\pi^0 \rightarrow \gamma \rightarrow e^\pm$	1.6×10^5	2.0×10^4	1.9×10^4	7.5×10^3	150	1.1
$\mu \rightarrow \gamma \rightarrow e^\pm$	1.3×10^6	8.7×10^4	21	0	0	0
Outer $\gamma \rightarrow e^\pm$	4.7×10^5	4.6×10^3	530	210	4	0.03
Muons outside the detector						
Outer $\gamma \rightarrow e^\pm$	3.5×10^4	N/A	360	152	3	0.02
$\pi^0 \rightarrow \gamma \rightarrow e^\pm$	43	N/A	43	18	0.4	0.003
Cosmic neutrons from the surface						
Outer $\gamma \rightarrow e^\pm$	1.5×10^3	N/A	230	81	1.6	0.01
$\pi^0 \rightarrow \gamma \rightarrow e^\pm$	3.4×10^3	N/A	2.4×10^3	890	18	0.13
$n, \eta, \Sigma \rightarrow \gamma \rightarrow e^\pm$	140	N/A	110	37	0.75	0.05
Total $e^\pm$ background events/yr						
	3.7×10^7	2.2×10^5	2.2×10^4	9.0×10^3	270	2.0

Schedule



- Technically driven. Current funding profile would add ~1 year
- We have up until CD2 (2-3 years) to seek commitments from other partners to build a near detector and move underground.

LBNE

Conclusions

- LBNE is proceeding rapidly, with a CD1 review in two weeks
- The collaboration is seeking international partners (and help from NSF) to expand the physics potential
- Work is continuing on cosmic ray backgrounds, but initial indications are that a surface option would work if sufficiently good reconstruction and light collection

Figure 12 summarizes the total cost as a function of the LAr-TPC far detector mass for various options. Cost estimates are described in more detail in the Engineering/Cost Working Group Report (http://www.fnal.gov/directorate/lbne_reconfiguration/).

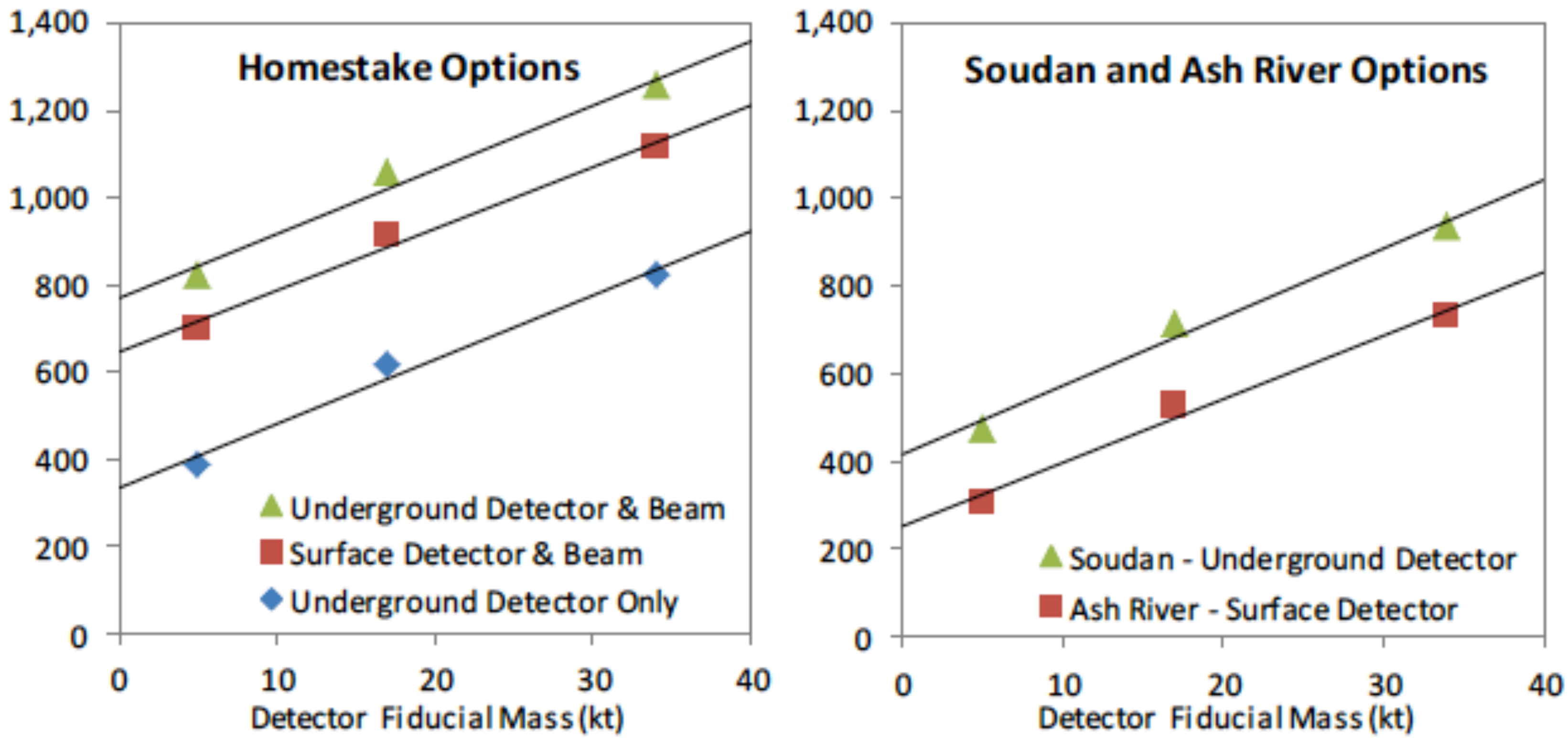


Figure 12. Cost estimates ($M), including contingency and escalation, as a function of LAr-TPC detector mass at Homestake (left) and Soudan and Ash River (right). Straight lines are linear fits.

Working Groups

Physics Working Group	Engineering / Cost Working Group
• Jeff Appel, FNAL (Scientific secretary) • Matthew Bass, Colorado State Univ. • Mary Bishai, BNL • Steve Brice, FNAL • Ed Blucher, U. Chicago • Daniel Cherdack, Tufts • Milind Diwan, BNL • Bonnie Fleming, Yale • Gil Gilchriese, LBNL • Zeynep Isvan, BNL • Byron Lundberg, FNAL • Bill Marciano, BNL • Mark Messier, Indiana U. • Stephen Parke, FNAL • Mark Reichanadter, SLAC • Gina Rameika, FNAL • Kate Scholberg, Duke U. • Mel Shochet, U. Chicago (Chair) • Jenny Thomas, UCL • Bob Wilson, U. Colorado • Elizabeth Worcester, BNL • Charlie Young, SLAC • Sam Zeller, FNAL	• Jeff Appel, FNAL (Scientific secretary) • Bruce Baller, FNAL • Jeff Dolph, BNL • Mike Headley, SURF • Tracy Lundin, FNAL • Marvin Marshak, U. Minnesota • Christopher Mauger, LANL • Elaine McCluskey, FNAL • Bob O'Sullivan, FNAL • Vaia Papadimitriou, FNAL • Mark Reichanadter, SLAC (Chair) • Joel Sefcovic, FNAL • Jeff Sims, ANL • Jim Stewart, BNL • Jim Strait, FNAL (Deputy Chair)

European Strategy Group Submission

Abstract The Long-Baseline Neutrino Experiment (LBNE) collaboration plans a comprehensive experiment that will fully characterize neutrino oscillation phenomenology using a high intensity 1300 km baseline accelerator neutrino beam and an advanced liquid argon TPC as the far detector. The goals for this program are well recognized to be the determination of leptonic CP violation, the neutrino mass hierarchy, and underground physics, including the exploration of proton decay and supernova neutrinos. The collaboration and the project are well organized and the U.S. Department of Energy has stated their intention to carry out this program in a phased manner. The scope of the initial phase focuses on accelerator neutrino physics and does not include deep underground placement of the far detector or the full near detector. The incremental cost of moving the phase 1 detector underground or of building a full-capability near detector complex are relatively modest: the cost of each of these is only about 15% of the LBNE phase 1 cost of ~US$800M. LBNE represents a substantial investment from the US in a frontier facility for high energy physics. Thus, there is significant opportunity for new collaborators to leverage this major investment and add substantial scientific scope. Collaboration on the design and construction of the far detector, near detector, or neutrino beam could provide sufficient additional resources to allow us, together, to place the far detector underground in the first phase, and include a sophisticated near detector which would not only improve the accuracy of the long-baseline oscillation measurements, but have rich physics program in its own right. In the following we describe the complete project as well as the phasing strategy.

ESPG document
https://indico.cern.ch/abstractDisplay.py/getAttachedFile?abstractId=150&resId=0&confId=175067

ESPG submission from Pier Oddone.
https://indico.cern.ch/abstractDisplay.py/getAttachedFile?abstractId=84&resId=0&confId=175067

Authors: Strait, Svoboda, Diwan, August 15, 2012